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Beyond Prices Versus Quantities

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Beyond Prices Versus Quantities

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Beyond Prices Versus Quantities

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Abstract: The reason structure-performance relationships are sensitive to the modelling of price or quantity as a decision variable is because of the consequences of the choice of decision variable for slope of the residual demand curve along which an individual firm maximizes profit. When one models profit maximization along a residual demand curve directly, important results of the literature on price-setting and quantity-setting firms (such as the impact of product differentiation on market efficiency or the private profitability of exogenous mergers) appear as special cases of more general results.

I. Introduction

Since Bertrand (1883) reviewed Cournot (1838), it has been understood that structure-performance relationships in oligopoly differ fundamentally depending on a particular kind of conduct: whether firms set price or quantity as a decision variable. The difference is most startling when the product is homogeneous, but that the difference is essential even if products are differentiated underlies many recent contributions to the literature.[1]

Yet it is odd that this should be so. We know, for example, that market performance under monopoly is invariant to changes in the firm's decision variable. Accepting the fact that 1 is a special number, what is it about the move from 1 incumbent to 2 that endows the price-quantity distinction with such importance?

In this paper, I argue that it is not the choice of the firm's decision variable that is of fundamental importance to the nature of structure-performance relationships in oligopoly. What is critical is not the firm's decision variable but what it thinks other firms' decision variables are. This in turn is important because it determines the nature of the firm's perceived residual demand curve.

Finally, I argue that if what is critical for structure-performance relationships is the nature of the firm's residual demand curve, then industrial economists ought to model the residual demand curve directly. By way of illustration, I apply a residual demand curve model of oligopoly to two of the standard questions of this

1. For example, Vives (1984), Singh and Vives (1984), Deneckere and Davidson (1985), Klemperer and Meyer (1988), and Majerus (1988).

literature: the impact of product differentiation on market efficiency and the impact of an exogenous merger on firm profitability.

II. Prices, quantities, and the residual demand curve

Consider a standard duopoly model. The product is differentiated, and inverse demand curves are linear:

(1a) $$p_1 = a - (q_1 + \theta q_2)$$

(1b) $$p_2 = a - (\theta q_1 + q_2)$$

θ is a product differentiation parameter, with $0 \le \theta \le 1$. If $\theta = 0$, the products of the two firms are independent in demand. As θ approaches one, the products of the two firms become better and better substitutes.[2] For simplicity, assume that marginal cost is constant, and without loss of generality assume that marginal cost is zero.

By inverting the system of inverse demand curves, one obtains the demand equations

(2a) $$(1 - \theta^2)q_1 = (1 - \theta)a + \theta p_2 - p_1$$

(2b) $$(1 - \theta^2)q_2 = (1 - \theta)a + \theta p_1 - p_2 .$$

(1) and (2) hold provided all prices and quantities are nonnegative, which is henceforth assumed.

The usual procedure to obtain firm 1's quantity reaction curve is to substitute (1a) in the definition of firm 1's profit, $\pi_1 = p_1 q_1$ to express firm 1's profit in terms of quantity alone. This procedure makes it natural to emphasize the role of quantity as a choice

2. In a N-firm oligopoly model presented below, I allow $\theta < 0$, which implies that varieties are complements in demand.

variable in determination of the nature of equilibrium. Suppose instead we adopt the equivalent formulation of treating firm 1 as maximizing profit p_1q_1 choosing both price and quantity, subject to (1a) as a constraint. This problem is analyzed by maximizing the Lagrangian

(3) $$\pounds = p_1q_1 + \lambda(a - q_1 - \theta q_2 - p_1)$$

with respect to p_1, q_1, and λ.

The first-order conditions that characterize an interior solution to (3) are

(4a) $$\frac{\partial \pounds}{\partial p_1} = q_1 - \lambda = 0.$$

(4b) $$\frac{\partial \pounds}{\partial q_1} = p_1 - \lambda = 0.$$

(4c) $$\frac{\partial \pounds}{\partial \lambda} = a - q_1 - \theta q_2 - p_1 = 0.$$

But these conditions together imply

(5) $$p_1 = a - q_1 - \theta q_2 = \lambda = q_1 ,$$

and this leads directly to the usual Cournot quantity-setting reaction function when products are differentiated.

By going through the same sort of exercise for firm 2, one obtains a quantity reaction function for firm 2. The two reaction functions together imply the usual equilibrium for quantity-setting firms, with the usual properties. But in this formulation of the model, firms are not quantity setters. They are profit-maximizers that believe their rivals hold quantity constant.

Now turn to what by abuse of terminology might be called the dual problem: maximize p_1q_1 subject to (2a) as a constraint. The corresponding Lagrangian is

(6) $$\Psi = p_1q_1 + \mu[(1 - \theta)a + \theta p_2 - (1 - \theta^2)q_1 - p_1] ,$$

with first-order conditions for an interior solution

$$\text{(7a)} \qquad \frac{\partial \Psi}{\partial p_1} = q_1 - \mu = 0$$

$$\text{(7b)} \qquad \frac{\partial \Psi}{\partial q_1} = p_1 - (1 - \theta^2)\mu = 0$$

$$\text{(7c)} \qquad \frac{\partial \Psi}{\partial \mu} = (1 - \theta)a + \theta p_2 - (1 - \theta^2)q_1 - p_1 = 0 \ .$$

From these first-order conditions, we have

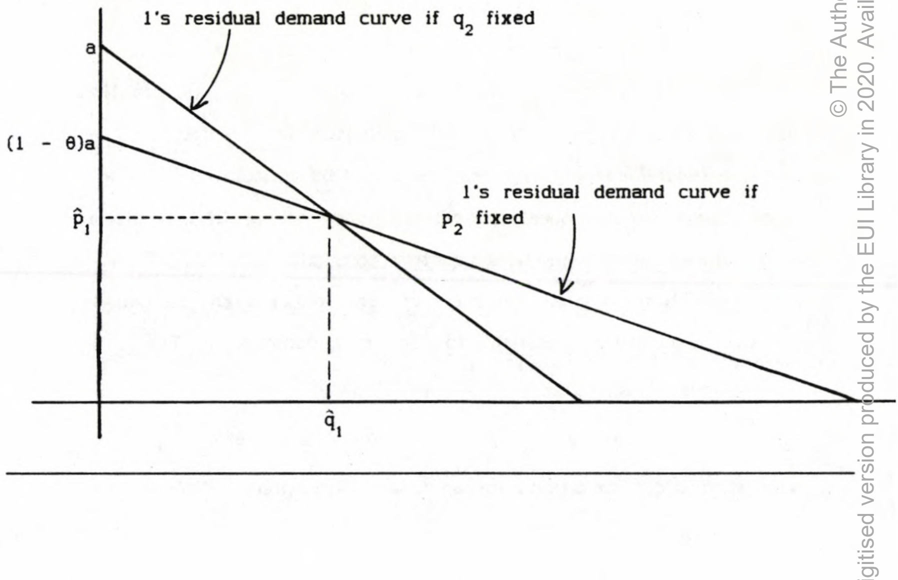
$$\text{(8)} \qquad \begin{aligned} p_1 &= (1 - \theta)a + \theta p_2 - (1 - \theta^2)q_1 \\ &= (1 - \theta)a + \theta p_2 - (1 - \theta^2)\mu = (1 - \theta)a + \theta p_2 - p_1 \ , \end{aligned}$$

and this leads directly to the usual equation of a price reaction curve when products are differentiated:

$$\text{(9)} \qquad 2p_1 = (1 - \theta)a + \theta p_2 \ .$$

By going through the same exercise for firm 2, one obtains the equation of the other price reaction curve. The two equations together imply the usual equilibrium for price-setting firms, with the usual properties. But in this formulation of the model, firms are not price-setters. They are profit-maximizers that believe their rivals hold price constant.

Figure 1: Firm 1 Alternative Residual Demand Curves



If it is not firm 1's decision variable that determines the nature of its reaction curve, what is it? It is firm 1's beliefs about the way its rival acts, which in turn determines the slope of firm 1's perceived residual demand curve.

Suppose firm 1 is at a point $(\hat{q}_1,\hat{p}_1)$ which is on the demand surface for the two varieties. If firm 1 believes that firm 2 holds q_2 constant, it acts in the belief that its residual inverse demand curve has equation (1a) and slope - 1 (figure 1). But if firm 1 believes that firm 2 holds p_2 constant, it acts in the belief that its residual inverse demand curve has equation (2a) and slope $-(1 - \theta^2)$.

The residual inverse demand curve of the duopolist that faces a price-setting rival is flatter-has a slope that is smaller in absolute value-than the residual inverse demand curve of the duopolist that faces or believes it faces a quantity-setting rival. It is this difference in slope-not whether a firm is modelled as selecting price or quantity-that determines the nature of structure-performance relationships.

III. Down the residual demand curve with gun and camera[3]

Models of price- and quantity-setting behavior differ because they imply that firms move along different residual demand curves. But if it is the nature of the residual demand curve that determines the nature of oligopoly equilibrium, why should industrial economists confine their attention to a choice between the two alternative

3. Apologies to Solow (1976).

residual demand curves implied by the beliefs that rivals hold either price or quantity fixed? Why not model the relationship between oligopoly equilibrium and the residual demand curve directly?

A. A residual demand curve duopoly model

I model firm i as maximizing profit along a a residual inverse demand curve with slope $-\alpha$,

(10) $$p_i = A_i - \alpha q_i ,$$

for $\alpha \geq 0$ and for $i = 1, 2$.[4] For a given residual demand curve, it makes no difference whether firm i is thought of as picking price or quantity: its profit-maximizing price, output pair will be the same under either specification.

Solution concept

What conditions should we require of equilibrium price-output pairs $(\hat{q}_1,\hat{p}_1)$ and $(\hat{q}_2,\hat{p}_2)$?

In standard oligopoly models, a firm's noncooperative equilibrium play maximizes its payoff, given the actions of all other firms. In addition, and independently of whether firms set prices or quantities, equilibrium prices and quantities clear the market. If firms set quantities, equilibrium prices are the prices firms expect to see for those quantities. If firms set price, equilibrium outputs are the quantities firms expect to sell at those prices.

For a residual demand curve oligopoly model, the corresponding requirements are that $\hat{q}_i$ are maximize

(11) $$\pi_i = (A_i - \alpha q_i)q_i$$

for $i = 1, 2$ and that $(\hat{q}_1,\hat{p}_1)$ and $(\hat{q}_2,\hat{p}_2)$ and be on the true demand

4. In a more general model, the slope parameter α would be allowed to differ from firm to firm.

surface, given by (1) or (2).

In the context of the model developed here, this is neither more nor less than the familiar concept of noncooperative equilibrium, of which it shares the strengths and weaknesses (for a discussion, see Johansen (1982)). If these conditions are satisfied, each firm is maximizing its expected payoff, and equilibrium values of price and output are consistent with the each firm's beliefs about price-output relationships. This justifies thinking of price-output combinations that satisfy these conditions as a noncooperative equilibrium.

Duopoly equilibrium

If $\hat{q}_i$ is to maximize (11), it must be that $\hat{q}_i = A_i/2\alpha$, or that $A_i = 2\alpha\hat{q}_i$. Thus if $(\hat{q}_i,\hat{p}_i)$ is to be optimal for firm i, the equation of firm i's perceived residual demand curve can be written

(12) $$p_i = 2\alpha\hat{q}_i - \alpha q_i ,$$

from which

(13) $$\hat{p}_i = \alpha\hat{q}_i.$$

for i = 1, 2.

The other requirement of equilibrium is that the combinations $(\hat{q}_1,\hat{p}_1)$ and $(\hat{q}_2,\hat{p}_2)$ lie on the true demand surface, which requires

(14a) $$\hat{p}_1 = \alpha\hat{q}_1 = a - \hat{q}_1 - \theta\hat{q}_2$$

(14b) $$\hat{p}_2 = \alpha\hat{q}_2 = a - \theta\hat{q}_1 - \hat{q}_2 .$$

Solving (14a) and (14b) gives equilibrium outputs:

(15) $$\hat{q}_1 = \hat{q}_2 = \frac{a}{1 + \alpha + \theta} ,$$

with implied equilibrium prices

(16) $$\hat{p}_1 = \hat{p}_2 = \frac{\alpha a}{1 + \alpha + \theta} .$$

If $\alpha = 1$, these reduce to the Cournot equilibrium values. If $\alpha = (1 - \theta^2)$, they become the Bertrand equilibrium values.[5]

B. Produce differentiation and market performance

Singh and Vives (1984) show that the relative efficiency of quantity-setting and price-setting competition depends on whether different varieties are substitutes or complements. It is instructive to examine the impact of demand relationships on market performance in the context of the present model.

In an N-firm version of the previous model, equilibrium firm output and price

(17a) $$\hat{q} = \frac{a}{1 + \alpha + (N - 1)\theta}$$

(17b) $$\hat{p} = \frac{\alpha a}{1 + \alpha + (N - 1)\theta}$$

A single firm's profit is therefore

(18) $$\pi = \frac{\alpha a^2}{[1 + \alpha + (N - 1)\theta]^2} .$$

New social welfare, the sum of consumers' surplus and firms' profit, is

(19) $$NSW = \frac{N}{2}(a + \hat{p})\hat{q} = \frac{Na^2}{2} \frac{1 + 2\alpha + (N - 1)\theta}{[1 + \alpha + (N - 1)\theta]^2} .$$

Taking the derivative of NSW with respect to α gives

(20) $$\frac{1}{Na^2} \frac{\partial NSW}{\partial \alpha} = - \frac{\alpha}{[1 + \alpha + (N - 1)\theta]^3} .$$

From equation (17), if $\theta > 0$, the denominator on the right is positive and the entire expression on the right is negative. In this model, increases in the slope of the residual demand curve worsen

5. If firm 2 maximizes profit along a residual demand curve of form (10), and firm 1 knows this and acts as a leader with respect to firm 2, then firm 1 produces monopoly output. This is the usual Stackelberg quantity leader result.

market performance. In this model, market performance is better, the flatter firms' perceived residual demand curves. (Recall that an increase in α from $1 - \theta^2$ to 1 corresponds to a move from Bertrand to Cournot oligopoly.)

IV. The private profitability of exogenous mergers

By way of illustrating the insights that are offered by the residual demand curve oligopoly model, I use it to address the questions of the private profitability of exogenous mergers.

It will be recalled that Salant et al. (1983) have shown that exogenous mergers in Cournot models will often be privately unprofitable for the merging firms, unless the merger includes a very high percentage of firms in the industry. The immediate cause of the lack of profitability is the reaction of firms outside the merger to output restriction by the post-merger firm. At a deeper level, it has been attributed to the fact that in Cournot models the post-merger firm's output restriction is unrealistically extreme (Perry and Porter, 1985). When the product is standardized, all firms in the post-merger Cournot market have the same equilibrium output.

Deneckere and Davidson (1985) have shown that exogenous mergers are privately profitable if firms set price.[6] Thus the exogenous merger literature is one of the areas where the price setter, quantity setter distinction appears to be fundamental. But even more fundamental is the slope of the residual demand curve along which firms believe they are maximizing profit.

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6. They use the Shubik (1980) model of price-setting firms with differentiated products.

(17a) and (17b) give equilibrium values for the N-firm residual demand curve model. For simplicity, let $\theta = 1$, so that products are homogeneous. Suppose $M < N$ firms merge, and that the post-merger firm maximizes

(21) $$\Pi = \sum_{i=1}^{M} (A_i - \alpha \sum_{j=1}^{M} q_j)q_i .$$

This specification implies that the post-merger firm understands demand relationships among the varieties it produces, but uses a perceived residual demand curve with slope $-\alpha$ to summarize demand relationships with varieties produced by other firms.

If the vector $(\hat{q}_1, \hat{q}_2, ..., \hat{q}_M)$ is to maximize (21), it must be that $A_i = 2\alpha(\hat{q}_1 + \hat{q}_2 + ... + \hat{q}_M)$. This in turn implies that $p_i = \alpha(\hat{q}_1 + \hat{q}_2 + ... + \hat{q}_M)$ and that in equilibrium

(22) $$(1 + \alpha)Mq_M + Fq_F = a ,$$

where q_M is equilibrium output of one division of the post-merger firm and q_F is equilibrium output of one of the F firms that stay outside the merger.

For a fringe firm, in equilibrium, the profit-maximization condition implies

(23) $$Mq_M + (F + \alpha)q_F = a .$$

From (22) and (23), post-merger equilibrium outputs are

(24a) $$q_F = \frac{a}{F + 1 + \alpha}$$

(24b) $$q_M = \frac{q_F}{M} .$$

Observe that the residual demand curve model demonstrates the same Cheshire-cat effect of merger that occurs Salant et al. (1983): the post-merger firm has the same equilibrium output as firms outside the merger. Equilibrium profit of one division of the post-merger firm is

$$\frac{\alpha}{M} \frac{a^2}{(F + 1 + \alpha)^2} . \tag{25}$$

Comparing (25) and the pre-merger profit of a single firm, an **exogenous merger is privately profitable** if

$$M \geq (F + \alpha)^2 . \tag{26}$$

Inequality (26) is more likely to be satisfied, the smaller is α-the flatter the firm's perceived residual demand curve. This makes perfect economic sense. If a firm maximizes profit along a residual demand curve that is very flat, then by merging it internalizes the impacts of output decisions by firms that are believed to be hard competitors on its own profitability. It is precisely when rivals are thought to be hard competitors that mergers ought to be expected to be profitable. That is what (26) implies.

If $\alpha = 1$, which is the Cournot residual demand case, then (26) is the condition for private profitability of an exogenous merger that arises in the Salant et al. (1983) model. If firms set price the residual demand curve is flatter than if firms set prices, it is more likely that (26) will be satisfied and therefore more likely that an exogenous merger will be profitable.[7] This is consistent with the results of Deneckere and Davidson (1985).

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7. This can be shown formally by allowing varieties to be less than perfect substitutes.

V. Final Remarks

Industrial economists have focused on the price-setter/quantity-setter distinction as a fundamental determinant of market performance. I show in this paper that the reason structure-performance relationships are sensitive to the use of price or quantity as a decision variable is because the choice of decision variables determines the slope of the residual demand curve along which an individual firm maximizes profit.

Whether a firm sets price or quantity is not of fundamental importance for structure-performance relationships. What is of fundamental importance is the slope of a firm's residual demand curve. When one models profit maximization along a residual demand curve directly, important results of the literature on price-setting and quantity-setting firms (such as the impact of product differentiation on market efficiency or the private profitability of exogenous mergers) appear as special cases of more general results.

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